Nutrient Criteria for Iowa Lakes

Recommended Criteria for Class “A” Recreational Uses

Report of the Nutrient Science Advisors

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Abbreviations

CWA – United States Clean Water Act
Chl-*a* – Chlorophyll-*a*
EPA – United States Environmental Protection Agency
ISU – Iowa State University
IDNR – Iowa Department of Natural Resources
LDA - linear discriminant analysis
μg/L – Microgram per liter [approximately parts per billion (ppb)]
mg/L – Milligram per liter [approximately parts per million (ppm)]
MPCA – Minnesota Pollution Control Agency
NSA – Nutrient Science Advisors
ppb – Parts per billion [approximately micrograms per liter (μg/L)]
ppm – Parts per million [approximately milligrams per liter (mg/L)]
RTAG – Regional Technical Assistance Group formed by Region VII, EPA
TN – Total Nitrogen
TP – Total Phosphorus
TSI – Carlson's trophic state index
UHL – University of Iowa Hygienic Laboratory

Introduction

At the request of the Director of the Iowa Department of Natural Resources (IDNR), Richard Leopold, the Nutrient Science Advisors (NSA) were assembled in June, 2007 to recommend nutrient criteria (magnitude, frequency and duration) for Iowa waters. The group included scientists actively researching subjects important to the topic including aquatic ecology, limnology, water chemistry, and human toxicity. IDNR invited staff responsible for acting on the group's recommendations. Because nutrient criteria are specific to different designated uses of Iowa waters, this report recommends nutrient criteria for Class A recreational lake uses. Criteria for other lake uses and for streams and rivers may differ. This document is the product of research and discussions among the NSA and was preceded by meetings of a Regional Technical Assistance Group (RTAG) assembled in 1999 by Region 7 of the United States Environmental Protection Agency (EPA) and a Technical Advisory Committee (TAC) assembled by IDNR in September 2006. The recommendations in this report are independent of these prior efforts, though our analysis includes some of the same data. A final report of the EPA RTAG is not yet available, but draft reports include nutrient benchmarks for lakes in EPA Region 7. These benchmarks are for total phosphorus, chlorophyll-*a*, and total nitrogen (Huggins et al. 2007) which will be discussed in the specific criteria section of this report. The IDNR TAC held two meetings (September 2006 and January 2007) but did not develop any criteria recommendations.

Included in this report are recommendations for Class A, recreational use of lakes. As described and defined in the *Iowa Water Quality Standards* (IAC 2006), Iowa surface waters can be designated for three types of Class A use: primary contact recreational use (Class A1), secondary contact recreational use (Class A2), and children's recreational use (Class A3). The recommendations in this document apply to all Class A recreational use. Existing uses related to aquatic life are limited to fish assemblages, therefore, recommendations for aquatic life uses will be considered after clarification by IDNR. .

Executive Summary

Water quality in the context of nutrients combines both aesthetic and safety issues and is determined by direct measures of phosphorus and nitrogen as well as responses to nutrients. Biological responses include amount of green algae and cyanobacteria (blue-green algae) present in the water column. Water transparency, an indirect biological response, is measured by the Secchi depth (m). Algae is measured as the density of chlorophyll *a* (Chl-*a*; µg/L) which indicates the amount of algal biomass, the source of some odors and toxins. The acceptable level of water quality, measured by Secchi depth and Chl-*a*, is determined partly through the subjective responses of Iowa residents surveyed about their experience and satisfaction using Iowa lakes, by analysis of data gathered for 131 Iowa lakes over a period of seven years beginning in 2000, and by comparison to data gathered in southern Minnesota and in other countries with climates and geology similar to Iowa.

Secchi depth and Chl-*a* levels that quantify water transparency, odor and potential cyanotoxins and determine water quality are themselves responses to levels of total phosphorus (TP) and total nitrogen (TN) present in the water. Once the NSA determined an acceptable level of water quality for Class A lakes measured as minimum Secchi depth and Chl-*a* levels, it was able to determine the level of TP and TN associated with corresponding values of response variables Secchi depth and Chl-*a*. Because of natural temporal variation in Iowa lakes, however, the NSA recommends that for lakes to be acceptable for Class A uses, these response and causal variable criteria only have to be met 75% of the time. Furthermore, since TP is the limiting factor for algal blooms in Iowa's nitrogen rich environment, we suggest applying the TP criteria to lakes first and applying the TN criteria only to those lakes that meet the TP criteria. The suggested criteria for Secchi depth and Chl-*a* and for the causal variables TN and TP represent a reasonable level that combines subjective expectations of Iowa lake users, scientific analysis, and regulatory standards in Minnesota and in other countries.

The NSA reached consensus on criteria applicable during the summer recreation season (between Memorial Day and Labor Day) for the response variables Secchi depth transparency and chlorophyll-a, as well as the two causal variables, TN and TP. For Class A lakes those criteria are:

Secchi depth of 1.0 m minimum.

Chl-*a** **concentration equal to or below 25 ppb (μg/L).

Mean TP concentrations equal to or below 35 ppb (μg/L).

TN concentrations less than or equal to 900 ppb (μg/L).

We need to protect the quality of the water in Iowa lakes to protect the health and safety of the people of all ages who swim and boat in these lakes, to protect the economic health of communities that depend, at least in part, on the satisfaction of the people who swim and boat in these lakes, and to protect the aesthetic value of Iowa lakes so that Iowans using their natural resources have as high quality an experience as possible. Levels of TP and TN above these standards risk the health and safety of the people using these lakes for direct contact recreation uses and threaten the economic health of the communities surrounding the lakes that have significant recreational industries.

Historical Levels of N and P in Iowa Lakes

Nitrogen (N) and phosphorus (P) are the critical macronutrients required by all plants. Potassium (K) is generally considered the third plant nutrient but has not been recognized as critical to managing aquatic ecosystems. Many aquatic organisms are affected by nutrient levels in surface waters, through direct or indirect pathways, which can adversely affect some aquatic life uses. Abundant N and P, in particular, stimulate excess production of phytoplankton such as algae and Cyanobacteria to the point that nuisance blooms can occur. These blooms can increase turbidity, impair recreational uses, lead to oxygen deficiencies that affect aquatic life, and generate toxins that affect both humans and aquatic organisms.

TP and TN are frequently used to measure nutrient levels because these are the measures that incorporate all forms of P and N that affect plant production. All chemical species of both elements are available to plants in the water column on time scales relevant to problems associated with excess nutrients. Characterization of the various forms of N (e.g. ammonia, nitrate, nitrite, Kjeldahl and organic N) and P (e.g., soluble and insoluble P) requires complex documentation and qualification of sampling conditions for the results to be useful for the purpose of developing recommendations for nutrient criteria.

The trophic state index (TSI) developed by Carlson (1977) is widely used to quantify nutrient states that range from oligotrophic (small biomass, clear water) through mesotrophic (moderate biomass) to eutrophic (much biomass) and ultimately hypereutrophic (extreme biomass). The trophic state of a lake is generally more closely regulated by concentrations of TP than TN, in part because N availability exceeds that of P in natural systems. This is not to say that N is not equally important in freshwater phytoplankton responses. In a literature review, Elser et al., (1990) concluded that "…both P and N were potentially limiting to algal growth…" in lakes that were fertilized with either of these nutrients. A very large mass of N is applied to the land surface or is released through soil disturbances each year throughout Iowa. The amount of N that is leached to groundwater and ultimately discharged to surface water bodies each year provides more than adequate amounts of N to support eutrophic and even hypereutrophic lake status when abundant P is available. While agricultural/urban activities certainly add nutrients to our surface waters, some data (Garrison, 1998 and Garrison, 2001) suggest that pre-settlement water quality conditions were eutrophic in our shallow natural lakes. Some Iowa lakes may have abundant N and P because of natural soil fertility in their watersheds.

Only limited information exists regarding either historical or pre-settlement levels of P in Iowa lakes. Paleoecological studies have been conducted at two Iowa lakes: Clear Lake in Cerro Gordo County (Garrison 1998) and Silver Lake in Delaware County (Garrison 2001). These studies use the analysis of lake sediment cores for diatom species to infer water quality conditions during the time periods represented by the cores. In addition to the two Iowa lake studies, the Minnesota Pollution Control Agency (MPCA) has used the analysis of lake sediment cores to infer pre-settlement phosphorus levels in Minnesota lakes based on an analysis of diatom species present. Results of these studies were used, in part, by MPCA to set nutrient criteria for Minnesota lakes (Heiskary and Wilson 2005). The results for southern Minnesota lakes are likely relevant for estimating pre-settlement nutrient conditions in the natural lakes of glacial origin in northern Iowa.

Studies of Clear Lake (Garrison, 1998) and Silver Lake in Iowa (Garrison, 2001), as well as studies of Minnesota lakes (Heiskary and Wilson, 2005:121), suggest that pre-settlement phosphorus levels in Iowa's natural lakes ranged from about 50 to 100 ppb, if we assume similarity between the geographically proximate northern Iowa and southern Minnesota systems. Pre-settlement levels were likely smaller in the deeper natural lakes and larger in shallower lakes. These results suggest that, prior to settlement, many of Iowa's natural lakes were likely eutrophic systems, with TP concentrations tending toward the middle and upper range accepted as representing classical eutrophy; i.e., from about 30 to 100 ppb (Moore and Thornton 1988).

Data and Methods Used

Data from the Iowa Lakes Study (Downing et al., 2005), part of an ambitious program sponsored by IDNR in cooperation with Iowa State University (ISU), were used to support these criteria recommendations. Three summer recreation season samples have been collected annually by ISU beginning in the year 2000 from 131 lakes. The "summer recreation season" is used in this document to mean the period between Memorial Day and Labor Day. The Lakes Study program also included a lake classification system (Joe Larscheid, 2007, written communication) to help identify Iowa lakes and impoundments most in need of restoration. As part of this system, lakes were classified using water quality scores for the 2000-2006 samples that varied from 0 (poor water quality) to 1 (high water quality). These scores were determined using linear discriminant analysis (LDA) and a predefined subset of the lakes which included both good (high quality) and poor (low quality) lakes. The LDA model produced a classification function that separated good and poor lakes using the following variables:

> Raw water quality score = - 5.0868 + 2.5857 (Secchi m) + 0.0078 (total phosphorus ppb) + 0.4803 (total nitrogen ppb) - 0.0008 (total suspended solids, mg/L) + 0.0267 (N:P ratio).

Data from IDNR's ambient water monitoring program were also used in the analysis. Since 2005, the University of Iowa Hygienic Laboratory (UHL) has collected and analyzed samples from the 131 lakes that were part of the Iowa Lakes Study. These samples have been collected and analyzed by the UHL using the same field methods as the ISU program and comparable laboratory methods. These data were collected during a period of April through October. In 2005 and 2007, three samples were collected in each of the 131 lakes, and five samples were taken in 2006 approximately monthly from May through September. To maintain consistency with the ISU Lakes Study program, only those UHL samples collected during the summer recreation season were used in the analyses.

This combination of water quality variables used in the LDA model (i.e., Secchi depth, TP, TN, and total suspended solids) separated the subset of good and poor lakes very well. In fact, most of the variation that separated good lakes from poor lakes was accounted for by this classification function (canonical correlation = 0.8626). Subsequently, the 131 monitored lakes were classified with this model. Raw quality scores were converted to a probability of membership in the predefined group of good lakes and ranged from 0-1. Lakes with a score of $\geq$0.75 were classified as "Good" water quality systems; lakes with a score from 0.25 - 0.75 were classified as "Fair" water quality systems; and lakes with low scores of $<$ 0.25 were classified as "Poor" water quality systems.

Another source of data was an assessment of the Iowa public's perception of swimmable water quality of Iowa lakes. This assessment was based on data collected by Iowa State University's Center for Agricultural and Rural Development and the Iowa State University limnology laboratory through funding by the EPA. Data were collected by sending questionnaires to a random selection of 8,000 Iowa residents following standard procedures. Respondents were asked a series of questions about the 131 monitored lakes to ascertain the respondents' economic valuation of recreational experiences at approximately 131 of Iowa's most important lakes.

Respondents were also asked to rank each lake visited using the EPA's water quality ladder (Fig. 1). Lakes judged by visitors to be swimmable would require a ranking of 6 or higher on this water quality ladder. Water quality estimates of these swimmable lakes used to support these criteria recommendations were summer averages for monitoring performed in 2003. The purpose of these analyses was to identify the water quality expectations of Iowa lake visitors with respect to water contact recreation.

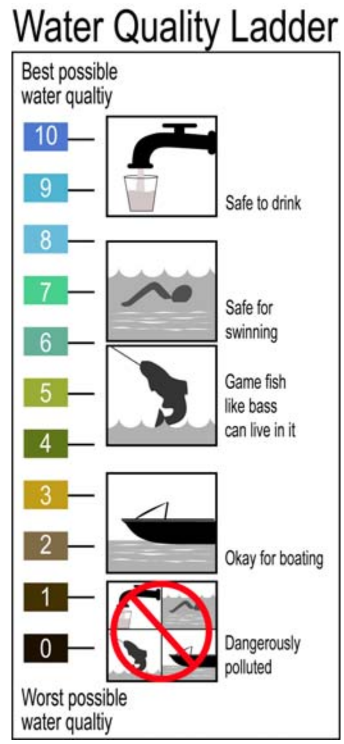


Figure 1. EPA Water Quality Ladder (Kneese, 1985)

The probability or risk of exceeding TP thresholds was used to establish a recommended TP concentration and threshold-exceedence frequency in the context of the response variables water transparency (Secchi depth) and Chl-*a*. The purpose of setting a water-quality criterion is to support a given water quality outcome as measured by a response variable. Implicit in the criterion is the understanding that violations of the criterion indicate the existence of, or the potential for, an adverse, worsening, or nuisance condition. Due to variability inherent in natural systems, there is some scientific difficulty in making strong predictive relationships between nutrient concentrations and adverse responses (e.g., unsafe transparency, nuisance blooms, Cyanobacteria dominance). In general, however, higher nutrient concentrations lead to increased risk of such adverse responses (Downing et al., 2001). Consequently, the criterion recommendations for TP included here are related to the risk of a response variable exceeding an average nuisance value.

Duration and frequency are important components of water-quality criteria. In addition to a threshold concentration (magnitude), the Clean Water Act (CWA) requires criteria to include the frequency with which that concentration must occur, and the duration or length of time a specific occurrence persists before a criterion is violated. Consequently, it is useful to identify the likelihood of having poor water-quality responses in relation to the likelihood of elevated levels of nutrients. Our ability to precisely quantify the likelihood of poor water quality depends largely on the frequency of monitoring. Anything empirical that can be determined about duration depends on the amount of time between samples. Iowa lake water-quality monitoring has included three samples per summer season with at least six seasons of data. So, for most of the 131 lake ecosystems monitored, at least 21 observations are available.

Specific criteria

Numerical nutrient water-quality criteria are quantitative estimates of the causative variables, TN and TP, and the response variables of water transparency and Chl-*a* are indicators of algal biomass. In the context of state water-quality standards, the three components of a water-quality criterion include a specific quantity (magnitude), as well as a duration during which the criterion applies, and frequency for which the criterion should be met. The magnitude criteria are presented as specific threshold values that distinguish water quality sufficient to protect recreational use. Frequency and duration components are incorporated by using cumulative frequency curves to define the probability or risk of exceeding the threshold.

Water transparency is important for human safety as well as critical to the penetration of light, the source of energy that ultimately drives ecosystems. Limited transparency reduces the lake users' ability to see hazards to swimming, diving, and wading as well as reducing the aesthetic appeal of lakes. Water transparency in lakes is commonly measured using a Secchi disk that determines how deep a person can see into the water. The disk is lowered into the lake attached to a calibrated chain or line until the observer loses sight of it. This depth is recorded and the disk is then raised until it reappears at which point the depth to the Secchi disk is read again. The average of the two readings is recorded as the Secchi depth.

Chlorophyll is the compound that colors plants and allows plants to synthesize organic compounds using energy from sunlight (photosynthesis). Chl-*a* is the green form and is one of the dominant types of plant pigments found in algae and Cyanobacteria. Consequently, Chl-*a* provides a convenient, consistent, and commonly measured indicator of algal biomass and Cyanobacteria production in a lake. It is important to limit blooms of phytoplankton (algae and Cyanobacteria) to fully support a lake's designated uses for primary contact recreation. Algal blooms are a nuisance because they limit visibility, produce unpleasant odors, and lead to excessive oxygen consumption. Cyanobacteria are important because under certain conditions, they can produce toxins, called "cyanotoxins," that present health risks. When ingested, cyanotoxins can produce nausea, vomiting, and diarrhea. Some of these toxins are among the most powerful natural poisons known and have no known antidotes (CDC, 2007). More severe ingestions may manifest decreased liver function, renal damage, abdominal pain, muscle aches, and oral blisters. Dermal contact can result in cold or flu-like symptoms, eye and ear irritation, rashes, and blistering under the swimsuit where cyanotoxins have been trapped, leading to prolonged skin contact in these areas. Inhalation or aspiration of toxins can produce cold- or flu-like symptoms, sore throat, and typical pneumonia-like symptoms.

Chl-*a* measurements would be a useful indicator of nuisance concentrations of Cyanobacteria. Unfortunately, several factors limit our ability to establish a specific criterion for Cyanobacteria. They frequently dominate (>50%) the phytoplankton biomass even when the total algal biomass is small (non-bloom status). Also, analytical problems with microcystins, the most commonly analyzed of the cyanotoxins, make it difficult to distinguish dissolved or extra-cellular cyanotoxins from those found within the living cells of Cyanobacteria. Consequently, it is difficult to specifically identify the dissolved cyanotoxins which are of greater concern for recreational contact from those found in living Cyanobacteria. The range of measured concentrations for dissolved cyanotoxins in all cases, except those where a major bloom is obviously breaking down, is 0.1-10 µg/L (WHO, 1999, p. 195). In the future, IDNR may consider adding a specific criterion for Cyanobacteria, microcystins, or other cyanotoxins as data become available.

Secchi Depth Transparency

The consensus of the NSA is that a Secchi depth less than 1.0 m in lakes is not compatible with primary body contact recreational use (Class A).

Recognizing natural variability in the quality of water of Iowa's lakes, Secchi depth may occasionally fail to meet 1.0 m even in lakes with good water quality. This recommended criterion must be met 75% of the time for purposes of determining whether a lake supports its designated Class A uses (Table 1). This frequency was defined using data from three samples in each of seven consecutive summer recreation seasons. The NSA recommends that the frequency be determined using a minimum of nine samples; three samples taken during each summer recreation season (see definition above) over at least three consecutive years. Consequently, lakes designated as Class A are understood to meet these minimum sample conditions and meet

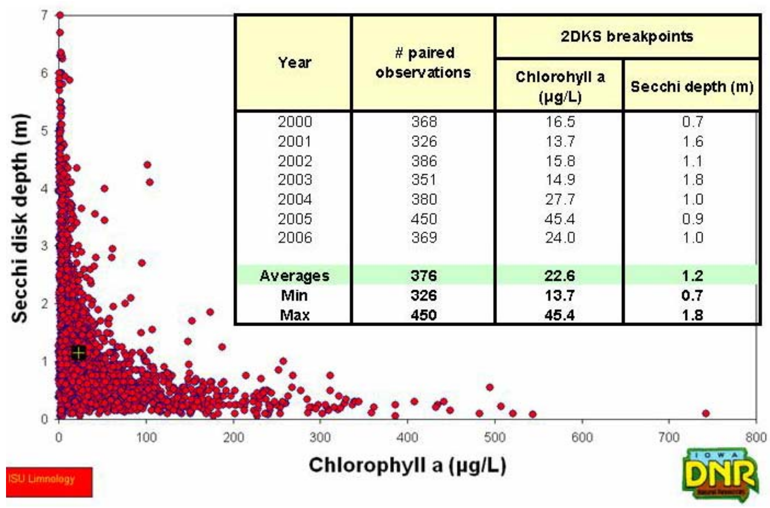
Year	June Samples		July Samples		August Samples		All Samples	
	Prob.	95% C.I	Prob.	95% C.I	Prob.	95% C.I	Prob.	95% C.I
Iowa Lakes classified as "Good" water quality systems								
2000	0.86	0.81-0.91	0.82	0.75-0.88	0.82	0.75-0.88	0.82	0.78-0.85
2001	0.86	0.81-0.91	0.95	0.94-0.97	0.95	0.94-0.97	0.94	0.93-0.95
2002	0.95	0.93-0.97	0.90	0.87-0.94	0.90	0.87-0.94	0.90	0.88-0.93
2003	1.00	1.00-1.00	0.95	0.93-0.97	0.95	0.93-0.97	0.94	0.92-0.95
2004	0.86	0.80-0.91	0.90	0.86-0.94	0.90	0.86-0.94	0.85	0.82-0.88
2005	0.96	0.94-0.97	0.92	0.89-0.95	0.92	0.89-0.95	0.86	0.83-0.89
2006	0.95	0.94-0.97	0.91	0.87-0.94	0.91	0.87-0.94	0.91	0.89-0.93
Totals	**0.92**	**0.91-0.93**	**0.91**	**0.89-0.92**	**0.91**	**0.89-0.92**	**0.89**	**0.88-0.90**
All Monitored Iowa lakes								
2000	0.34	0.30-0.38	0.29	0.25-0.33	0.29	0.25-0.33	0.31	0.29-0.33
2001	0.62	0.58-0.66	0.62	0.57-0.66	0.54	0.50-0.58	0.59	0.57-0.62
2002	0.60	0.56-0.64	0.38	0.34-0.43	0.28	0.24-0.31	0.42	0.39-0.44
2003	0.65	0.61-0.69	0.46	0.42-0.50	0.34	0.30-0.38	0.48	0.46-0.51
2004	0.43	0.39-0.48	0.42	0.38-0.46	0.32	0.28-0.36	0.39	0.37-0.42
2005	0.58	0.55-0.62	0.41	0.37-0.45	0.24	0.21-0.27	0.41	0.39-0.43
2006	0.50	0.46-0.54	0.39	0.35-0.43	0.31	0.27-0.35	0.40	0.38-0.43
Totals	**0.53**	**0.52-0.55**	**0.42**	**0.41-0.44**	**0.33**	**0.32-0.34**	**0.43**	**0.42-0.44**

Table 1. Probability of monitored Iowa lakes achieving a Secchi disk depth of at least 1.0 m.

the criterion magnitude in least 75% of the samples. This attainment frequency was supported by studies showing that customer loyalty (e.g. repeated lake users) can only be assured by extremely high satisfaction levels as measured on a Likert scale of five levels (Mittal and Lassar, 1998). These researchers found that as many as 67% of customers whose satisfaction was rated four (4) on the Likert scale were willing to switch to a competitor (e.g., alternative recreation). We can infer from this research that a perfect score of Likert 5 seems necessary to avoid a substantial majority of users seeking an alternative lake. We concluded that meeting our recommended criterion 100% of the time to completely satisfy users' expectations (Likert 5) was unreasonable given the natural temporal variability of nutrient concentrations in lakes. Similarly, meeting our recommended criterion 50% of the time may satisfy only a few users. Thus, a minimum level of "satisfied" (something better than neutral) would need to be 75% to avoid a negative perception of lake water quality that would drive many lake users away from a particular lake. This frequency of meeting our criterion is also consistent with the reference condition approach recommended by U.S. EPA (2000) for lake and reservoir nutrient criteria. Taking this approach, the 25th percentile Secchi depth value from reference site sampling data (75% attainment level) would be considered a suitable criterion. This criterion is typically met by a group of Iowa lakes rated as having good water quality that may be considered reference lakes (Appendix 1). Except during 2000, Iowa lakes with good quality water, as identified through IDNR lakes classification study, met this criterion when three summer samples each of the last seven years were analyzed (Table 1).

The NSA's recommendation for Secchi depth was determined by combining a number of lines of evidence. Evidence that supports transparency criteria of 1.0 m include:

- 1 m coincides with adult waist depth that could be considered a minimum to avoid a visible hazard.
- Carlson's Trophic State Index (TSI) relates transparency depths less than 1.0 m to hypereutrophy (Carlson and Simpson, 1996), a trophic state marked by algal blooms to be avoided in lakes used for direct contact recreation.
- A natural breakpoint in plotting Secchi depth and Chl-*a* occurs at a depth of 1.2 m (Fig. 2) which coincides with an average Chl-*a* concentration of about 23 µg/L. Breakpoints are critical thresholds where the relationships between two variables change as described by the two-dimensional, non-parametric Kolmogorov–Smirnov test (2D KS). Thus, lakes with Chl-*a* concentrations < 23 ppb are associated with water clarity ranging from very clear water (large Secchi) to turbid water (small Secchi). Whereas, lakes with Chl-*a* concentrations > 23 ppb have a very low probability of clear water conditions (Secchi readings < 1.2 m).



Year	# paired observations	2DKS breakpoints	
		Chlorophyll a (µg/L)	Secchi depth (m)
2000	368	16.5	0.7
2001	326	13.7	1.6
2002	386	15.8	1.1
2003	351	14.9	1.8
2004	380	27.7	1.0
2005	450	45.4	0.9
2006	369	24.0	1.0
Averages	**376**	**22.6**	**1.2**
Min	**326**	**13.7**	**0.7**
Max	**450**	**45.4**	**1.8**

Figure 2. 2-D Kolmogorov-Smirnov test showing the natural break point between Secchi depth and Chl-a at an average depth of 1.2 m and Chl-*a* concentration of 22.6 µg/L for Iowa lake data from 2000-2006 .

- Secchi disk transparency has been directly correlated to lakefront property values in Maine (Michael et al., 1996) and Minnesota (Steinnes, 1992). Decreased transparency below 1.0 m resulted in as much as 22% loss of property value.
- The public perception survey of Iowa lakes shows that a transparency of 1.4 m or greater is expected of swimmable lakes (Downing et al., 2006). Summary statistics of the Secchi transparency depths that were measured in lakes ranked as $\geq$ 6 on the EPA water quality ladder (Fig. 1) are shown in the box at right.

Mean = 1.8
Median = 1.4
25^{th} % ile = 0.9
15^{th} % ile = 0.7
5^{th} % ile = 0.3
Secchi transparency of lakes (m) ranked as swimmable by 2003 lake visitors.

- The relationships between TP, Chl-*a* and Secchi transparency have been well established for Minnesota (Heiskary, 1997). As Secchi disk transparency decreases below 1 m, there is an increased frequency of users who perceive lakes to be unsuitable for swimming.
- In North Dakota, Rice Lake, a shallow lake used for swimming while maintaining a viable fishery, is expected to average a Secchi disk transparency of at least 1 m (Tetra Tech, 2002).

- Danish lakes with Secchi depths less than 1 m would be classified as poor or bad (Sondergaard, et al., 2005) and in other European countries Secchi depths less than 2 m would be classed poor or bad (Moss et al. 2003) using the ecological classification proposed by the European Water Framework Directive.

Chlorophyll- *a*

The consensus of the NSA is that a Chl-*a* concentration greater than 25 ppb (µg/L) is not compatible with Class A primary body contact recreational use.

Because of natural factors in Iowa's lakes, Chl-*a* may occasionally fail to meet the 25 ppb (µg/L) criterion even in lakes with good water quality. However, the criterion must be met 75% of the time to support Class A uses in Iowa lakes. This frequency was defined with data from three samples in each of seven consecutive summer recreation seasons. The NSA recommends that the frequency be determined using a minimum of nine samples; three samples taken during each summer recreation season (see definition above) in at least three consecutive years. Consequently, lakes designated as Class A are understood to meet these minimum sample conditions for Chl-*a* in at least 75% of the samples. This attainment frequency was based on minimum levels needed for "satisfied" users (see discussion above), and needed to be at least 75% to avoid a negative perception of lake water quality that would drive many lake users away from a particular lake. This attainment frequency is also consistent with the reference condition approach recommended by EPA (2000) for lake and reservoir nutrient criteria. Taking this approach, the 75th percentile Chl-*a* concentration from reference site sampling data would be considered a suitable criterion. This criterion is typically met by a group of Iowa lakes rated as

Year	Period 1		Period 2		Period 3		All periods	
	Prob.	95% C.I	Prob.	95% C.I	Prob.	95% C.I	Prob.	95% C.I
Iowa Lakes classified as "Good" water quality systems								
2000	1.00	1-1	0.95	0.94-0.97	0.95	0.94-0.97	0.97	0.96-0.98
2001	1.00	1-1	0.82	0.75-0.88	0.91	0.87-0.94	0.91	0.89-0.93
2002	0.95	0.93-0.97	0.95	0.93-0.97	0.81	0.74-0.88	0.90	0.88-0.93
2003	1.00	1-1	0.95	0.93-0.97	0.86	0.81-0.91	0.94	0.92-0.95
2004	0.90	0.87-0.94	0.85	0.79-0.91	0.75	0.67-0.83	0.84	0.8-0.87
2005	0.67	0.58-0.76	0.58	0.48-0.68	0.38	0.28-0.47	0.54	0.48-0.6
2006	0.91	0.87-0.94	0.82	0.75-0.88	0.82	0.75-0.88	0.85	0.82-0.88
Totals	**0.92**	**0.9-0.93**	**0.84**	**0.82-0.86**	**0.78**	**0.75-0.8**	**0.84**	**0.83-0.86**
All Monitored Iowa lakes								
2000	0.63	0.59-0.67	0.75	0.72-0.78	0.77	0.74-0.8	0.72	0.7-0.74
2001	0.86	0.84-0.88	0.65	0.61-0.69	0.52	0.47-0.56	0.68	0.66-0.7
2002	0.72	0.69-0.76	0.42	0.37-0.46	0.41	0.37-0.45	0.51	0.49-0.54
2003	0.81	0.78-0.83	0.77	0.74-0.8	0.48	0.44-0.52	0.69	0.66-0.71
2004	0.60	0.56-0.64	0.43	0.39-0.47	0.30	0.27-0.34	0.44	0.42-0.47
2005	0.43	0.39-0.47	0.25	0.22-0.28	0.14	0.12-0.16	0.27	0.25-0.29
2006	0.54	0.5-0.58	0.45	0.41-0.49	0.32	0.28-0.36	0.44	0.41-0.46
Totals	**0.65**	**0.63-0.66**	**0.52**	**0.51-0.54**	**0.42**	**0.4-0.43**	**0.53**	**0.52-0.54**

Table 2. Probability of monitored Iowa lakes achieving a Chl-*a* concentration of not more than 25 ug/L.

having good water quality that may be considered reference lakes (Appendix 1). With the exception of the years 2004 and 2005, twenty-two Iowa lakes classified as having good water quality systems through IDNR lake classification study met this criterion when three summer samples each of the last seven years were analyzed (Table 2).

The multiple lines of evidence relevant to Chl-*a* levels suggest a range of potential criteria levels, some lower and some higher than that recommended by the NSA. This recommendation for Iowa's lakes, for example, is larger than the 8.0 µg/L (ppb) recommended for EPA's Region 7 by the RTAG (Huggins, et al., 2007). The RTAG recommendation, however, included protection of aquatic life uses, which may require a smaller Chl-*a* concentration. Our recommended criterion represents a reasonable compromise between conflicting evidence, and it is strongly influenced by the natural breakpoint between Secchi depth and Chl-*a* levels (Fig. 2). The evidence that led to the Chl-*a* criterion includes:

- A natural breakpoint occurs at about 23 µg/L Chl-*a* when plotted against Secchi depth, based on data from Iowa lakes (Fig. 2).
- Carlson's TSI defines eutrophic conditions equivalent to 7.3-20 µg/L (ppb) Chl-*a* and greater than 20 ppb (µg/L) Chl-*a* as hypereutrophic (Carlson and Simpson, 1996), conditions that will be useful in considering aquatic life uses.
- Chl-*a* concentrations of 20-30 µg/L (ppb) define a severe nuisance (Walmsley, 1984) based on a frequency analysis rather than mean annual or warm-season mean values.
- Hypereutrophic conditions are initially attained in impoundments where Chl-*a* is between 16 and 21 µg/L (Walmsey, 1984).
- Concentrations between 36 and 60 µg/L (ppb) Chl-*a* correspond to a maximum phytoplanktonic population when light is limited through self-shading in the upper 5 m (Steeman-Nielsen, 1962 and Talling, 1965 in Walmsey, 1984).
- Florida defines an algal bloom as conditions with 40 µg/L (ppb) Chl-*a* (Bachmann et al., 2003). This is a maximum concentration that, when exceeded, will produce undesirable consequences.
- The public perception survey of Iowa lakes shows that, on average, lakes were considered to be swimmable only if the Chl-*a* concentration was less than about 17 µg/L (ppb). (Downing et al., 2006). Summary statistics of the Chl-*a* concentration measured in lakes ranked as ≥ 6 on the EPA water quality ladder (Fig. 1) are shown in the box at right.
- Chl-*a* concentrations that exceed 21 µg/L (ppb) in Danish lakes (Sondergaard, et al., 2005) would be classified as poor or bad and those that exceed 30 µg/L (ppb) in other European countries would be classed poor or bad (Moss, et al,, 2003) using the ecological classification proposed by the European Water Framework Directive.
- This Chl-*a* criterion also provides a limit on Cyanobacteria within the context of overall limits on algal blooms.

Mean = 18.6
Median = 17.2
25th % ile = 24.7
15th % ile = 27.9
5th % ile =34.0
Chl-*a* concentrations (µg/L) in lakes ranked as swimmable by 2003 lake visitors.

Total Phosphorus

In lakes classified for primary body contact recreational use (Class A), mean TP concentrations that do not exceed 35 ppb during the summer recreation season assure the recommended Chl-*a* criterion of 25 ppb and the water transparency criterion of Secchi depth > 1.0 m will be met at least 75% of the time. Thus, poor water quality would be observed less than ¼ of time.

The recommended criterion was based on an analysis of data from six years of summer season sampling on 131 Iowa lakes. The recommended criterion for TP was based on its relationships between the two response variables, Secchi depth and Chl-*a*, and the consequent risk of unacceptably high levels of Chl-*a* or unacceptably poor water transparency. The risk was calculated as the frequency of Secchi transparency estimated as <1 m, or the frequency of Chl-*a* estimated as >25 ppb, divided by the total number of estimates made during the summer seasons of, in this case, 2001-2006 (Fig. 3). TP concentrations are graphed as the arithmetic mean of estimates from the upper mixed zone made throughout the same period. Lines are moving averages of 21 estimates to show overall trends. There is a 25% likelihood that poor water quality will occur under either of these measures at approximately 35 ppb of TP.

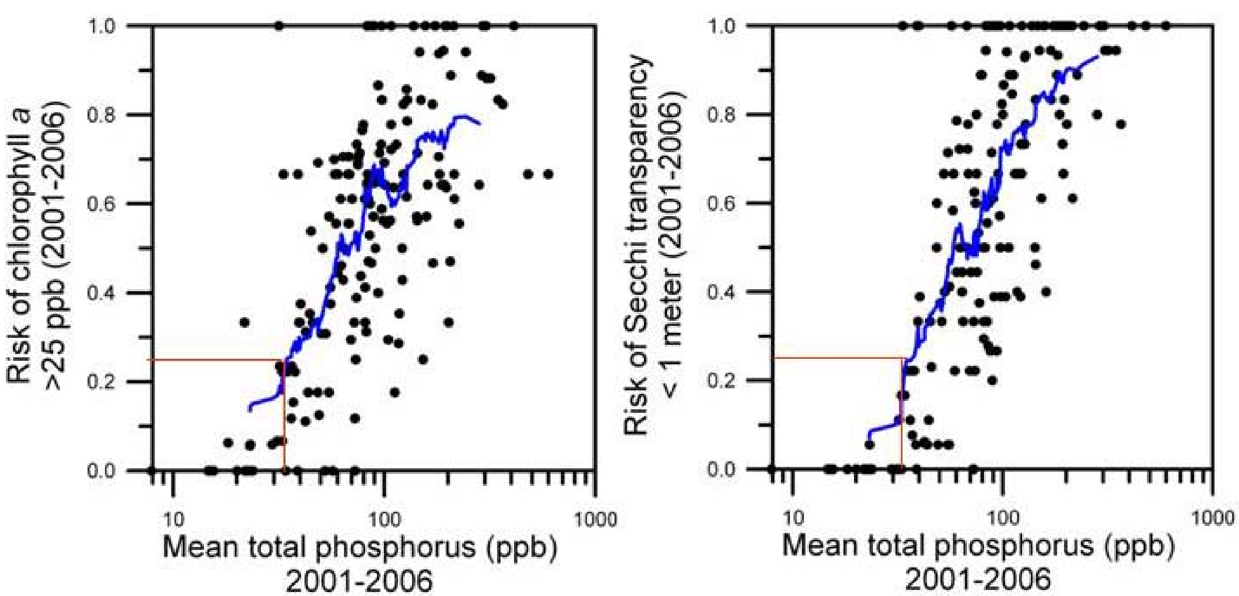
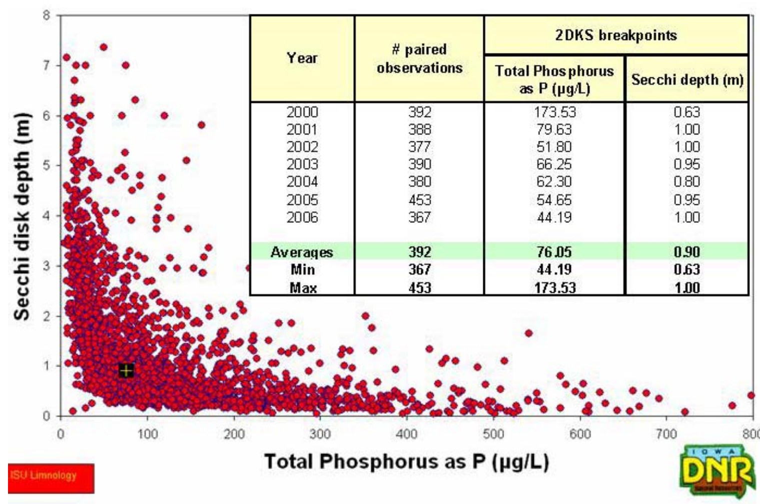


Figure 3. Risk of Chl-*a* exceeding 25 ppb and Secchi depth < 1 m related to TP in Iowa Lakes. Horizontal red line represent 25% risk of exceeding criteria and vertical red line is the intercept with the TP axis.

The NSA favors this way of developing the criteria recommendation for TP. At the 75% risk level, visitors to lakes will, on average, encounter conditions poorer than 1 m Secchi or 25 ppb Chl-*a* only 25% of the time. Further, for a given TP level, this will underestimate the occurrence of unacceptable conditions for about half the lakes and over-estimate such conditions for the other half. Thus, a TP concentration of 35 ppb seems a fair estimate of the concentrations at which one finds good water quality sufficiently frequently to satisfy documented acceptable social limits (see discussion under Chl-*a* and transparency).

Other evidence that supports TP values at least as small as the recommended criterion value includes:

- This recommendation equals that recommended for EPA Region 7 lakes by the RTAG (Huggins, et al., 2007), and is confirmed with direct measurements of the conditions in Iowa lakes.
- Minnesota data show that the greatest changes in Secchi transparency occur between 10 and 50 µg/L TP (Heiskary, 2005) with smaller changes between 40 and 50 µg/L TP. The recommendation of the NSA is within the range where greater transparency changes occur, providing protection from changes in transparency that could exceed the recommended limit.
- Walker (1984) produced equations that predict bloom frequency using the mean-annual Chl-*a* concentration that defines a mean growing season TP target needed to avoid that frequency. The frequency of algal blooms was 0% when TP concentrations were < 30 µg/L. The probability of algal blooms increased to 70% when TP concentrations were 100-120 µg/L (Heiskary and Wilson 2005). Algal blooms were defined as having concentrations of Chl-*a* exceeding 30 µg/L (Heiskary and Wilson 2005).
- Data from Iowa lakes show that 76 ppb TP is definitively associated with the upper limit of clear water. Smaller TP concentrations are related to greater probability of clear water that is the basis for the NSA recommendation. A natural break point exists at about 76 ppb (µg/L) TP when plotted against Secchi depth using a 2-D Kolmogorov-Smirnov test (Fig. 4). In this case, lakes with TP concentrations ≤ 76 ppb are associated with the complete range of water clarity possibilities from very clear water (large Secchi) to turbid water (small Secchi) conditions. Recommending a criterion of 35 ppb TP provides an increased opportunity to have clear water 75% of the time. Lakes with TP concentrations > 76 ppb have a very low probability of the clear water conditions desired by surveyed Iowans.



Year	# paired observations	2DKS breakpoints	
		Total Phosphorus as P (µg/L)	Secchi depth (m)
2000	392	173.53	0.63
2001	388	79.63	1.00
2002	377	51.80	1.00
2003	390	66.25	0.95
2004	380	62.30	0.80
2005	453	54.65	0.95
2006	367	44.19	1.00
Averages	**392**	**76.05**	**0.90**
Min	**367**	**44.19**	**0.63**
Max	**453**	**173.53**	**1.00**

Figure 4. 2-D Kolmogorov-Smirnov test showing a natural break point between Secchi depth and TP at an average depth of 0.9 m and TP concentration of 76 ppm for Iowa Lake data from 2000-2006.

Total Nitrogen

The consensus of the NSA is that a TN concentration greater than 900 ppb (µg/L) is not compatible with Class A primary body contact recreational uses of Iowa lakes.

This concentration is appropriate to meet the recommended Chl-*a* criterion of 25 ppb (µg/L) and the water transparency criterion of Secchi depth <1.0 m at least 75% of the time. Thus, poor water quality would be observed less than ¼ of the time. The TN criterion will only be applied to lakes that satisfy the TP criterion.

The recommended criterion was based on an analysis of data from seven years of summer season sampling of 131 Iowa lakes (Fig. 5), and a scientific assessment of the relationships among TP, TN and nuisance algal growth in freshwater lakes. In Iowa lakes, as with most lakes worldwide (Downing and McCauley, 1992), those with high levels of TP, also have high levels of TN. Independent of this fact, as shown in Fig. 5, is when TN <900 ppb (µg/L) or 0.9 ppm, visitors to lakes will, on average, encounter conditions poorer than 1 m Secchi or 25 ppb Chl-*a* only 25% of the time. There is also evidence that, in the past, the growth of aquatic vegetation in some lakes was controlled by naturally occurring inputs of nitrogen (Schindler, 2006). The NSA believes that in Iowa lakes fitting this description, current TP and TN indicate these lakes were transformed to phosphorus-limited systems by increased inputs (by weight) of anthropogenic

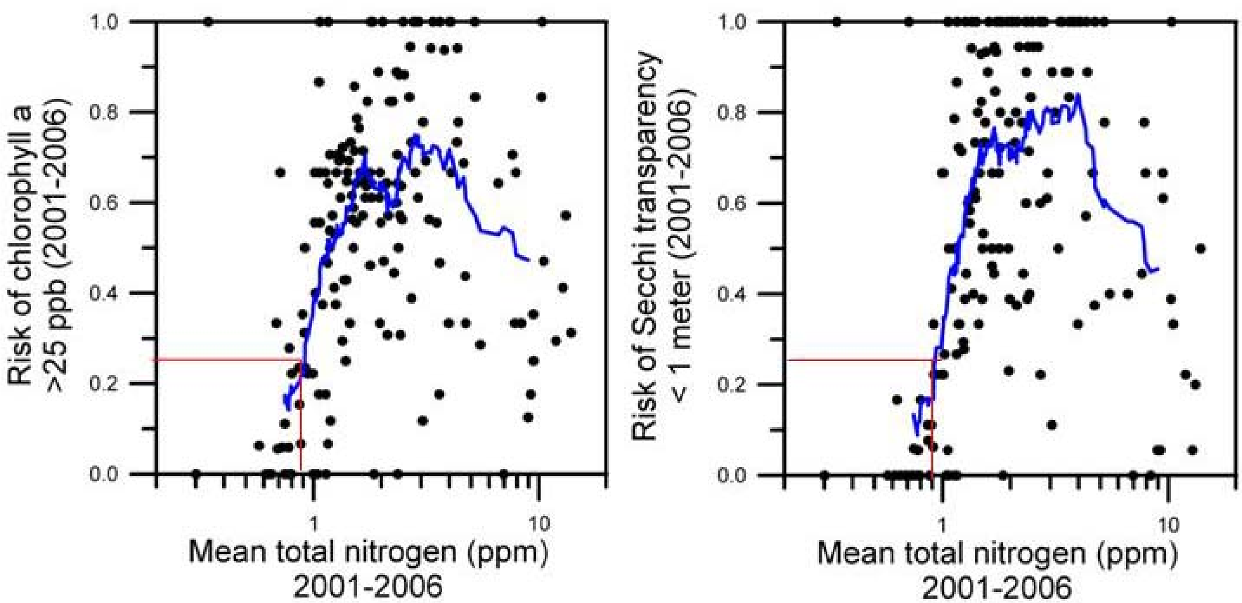


Figure 5. Risk of Chl-*a* exceeding 25 ppb and Secchi depth < 1 m related to TN in Iowa Lakes. Horizontal red line represent 25% risk of exceeding criteria and vertical red line is the intercept with the TN axis.

nitrogen far exceeding inputs of anthropogenic phosphorus. When phosphorus limits algal growth, controlling TP will have the most positive impact on water quality in Iowa lakes. Downing and McCauley (1992) also explain that lakes with the highest water quality (lowest TP) are more susceptible to changes in quality from anthropogenic sources of N and P. This is due to rapid shifts in the water column ratio of TN:TP. The TN:TP ratio in lakes is a generally accepted indicator of the nutrient that is most likely to control the growth of nuisance algae. Thus, to ensure that lakes meeting the TP criterion do not succumb to nitrogen-stimulated nuisance algal blooms, the TN criterion should also be applied.

Summary

The NSA reached consensus on criteria for two response variables, Secchi depth transparency and Chl-*a*, as well as two direct variables, TN and TP that are recommended for Class A lake uses.

Secchi depth of less than 1.0 m is not compatible with this use. This criterion magnitude must be met 75% of the time during the summer recreation season for purposes of determining whether a lake supports its designated Class A uses.

Chl-*a* concentrations that exceed 25 ppb (µg/L) are not compatible with this use. This criterion magnitude must be met 75% of the time for purposes of determining support of Class A uses in Iowa lakes.

Mean TP concentrations that exceed 35 ppb during the summer recreation season assures the recommended Chl-*a* and Secchi depth criteria will be met at least 75% of the time.

TN concentrations that exceed 900 ppb (µg/L) in lakes during the summer recreation season are not compatible with Class A uses in lakes that satisfy the TP criterion.

The NSA recommends that the frequencies associated with the response variables be determined using a minimum of nine samples; three samples taken during each summer recreation season (see definition above) over at least three consecutive years. Consequently, lakes designated as Class A are understood to meet these minimum sample conditions and meet the magnitude criteria in least 75% of the samples.

These criteria are intended to protect primary body contact (Class A) recreational use. The criteria recommendations apply to all Class A lakes, regardless of lake-to-lake differences in hydro-morphometric factors such as lake origin, depth, hydraulic retention time, and watershed area. Monitoring data from the past seven years indicate that many Iowa lakes will fail to attain the recommended criteria. For example, based upon data from all 131 monitored lakes and sampling periods combined, the Secchi depth criterion was met just 43% of the time during the summer recreational season (Table 1). The level of attainment for lake systems classified as “good” was 89% during the seven-year monitoring period compared with just 36% for lakes rated as “fair” or “poor” water quality systems

The NSA believes the criteria are appropriate for Class A lake use, and reflect scientific information currently available to the group. Additional research initiatives, if successfully completed, will enable IDNR to refine the understanding of nutrient concentrations and the frequency and duration of undesirable concentrations in lakes already being studied and a larger number of lakes. This research and ongoing monitoring will be required to implement these or any criteria.

Research Needs

1-- Paleolimnological studies of sediment diatoms in Iowa's natural lakes and wetlands should be completed to obtain estimates of pre-settlement phosphorus levels. These results will aid in defining natural aquatic ecosystems and the associated range of phosphorus concentrations needed to define nutrient criteria for aquatic ecosystems.

2-- Intensive sampling of a small group of lakes is recommended to provide an in-depth understanding of processes affecting nutrient supply and response dynamics. Sampling intensity should be sufficient to examine daily changes in nutrient concentrations and nutrient response variables over a sustained period of time encompassing both dry and wet climate cycles. This research should be conducted in a group of lakes representing a gradient from low to high nutrient levels that allow an evaluation of nutrient uptake under scarce and excess nutrient supplies. Stoichiometric N and P relationships in the water column and algal tissue should be examined for the purpose of characterizing lake conditions in which N and P are limiting to primary producers.

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Appendices

Appendix 1. Lakes included in the DNR lake-classification study excluding Coralville, Rathbun, Red Rock and Saylorville reservoirs.

ID	Name	County	Type	Avg. Depth (m)	Avg. depth (ft)	Lake Area (acres)	Watershed Area (acres)	Watershed to Lake Area Ratio	Watershed to Lake Volume Ratio	Water quality rating
3	Arrowhead Lake	Sac	Surface Mine	2.8	9.1	33	317	9.5	1.0	Good
10	Big Spirit Lake	Dickinson	Natural	5.2	17.0	5373	17170	3.2	0.2	Good
26	Dale Maffitt Reservoir	Polk	Constructed	8.0	26.3	197	703	3.6	0.1	Good
38	George Wyth Lake	Black Hawk	Surface Mine	2.8	9.1	44	440	9.9	1.1	Good
39	Green Belt Lake	Black Hawk	Surface Mine	3.6	11.8	18	24	1.3	0.1	Good
40	Green Castle Lake	Marshall	Constructed	2.9	9.6	16	265	16.7	1.7	Good
50	Lacey Keosauqua Park Lake	Van Buren	Constructed	3.6	11.7	23	737	32.6	2.8	Good
55	Lake Geode	Henry	Constructed	7.2	23.7	190	10136	53.4	2.3	Good
71	Lake Wapello	Davis	Constructed	3.9	12.9	280	4764	17.0	1.3	Good
73	Little Sioux Park Lake	Woodbury	Surface Mine	3.1	10.3	11	62	5.7	0.6	Good
86	Moorehead Park Pond	Ida	Constructed	4.0	13.2	10	507	49.6	3.7	Good
87	Mormon Trail Lake	Adair	Constructed	4.2	13.8	34	384	11.4	0.8	Good
88	Nelson Park Lake	Crawford	Constructed	2.8	9.2	11	600	52.6	5.7	Good
89	Nine Eagles Lake	Decatur	Constructed	4.1	13.4	62	1049	16.9	1.3	Good
91	Oldham Lake	Monona	Constructed	3.0	10.0	15	688	44.4	4.5	Good
95	Pleasant Creek Lake	Linn	Constructed	5.0	16.3	418	2060	4.9	0.3	Good
96	Poll Miller Park Lake	Lee	Constructed	3.7	12.2	17	254	14.7	1.2	Good
109	Slip Bluff Lake	Decatur	Constructed	3.9	12.7	20	240	12.2	1.0	Good
116	Three Mile Lake	Union	Constructed	5.0	16.3	797	21925	27.5	1.7	Good
125	West Okoboji Lake	Dickinson	Natural	11.5	37.7	3867	15157	3.9	0.1	Good
129	Willow Lake	Harrison	Constructed	3.8	12.6	27	487	18.2	1.4	Good
132	Yellow Smoke Park Lake	Crawford	Constructed	3.3	10.8	40	1496	37.6	3.5	Good
1	Arbor Lake	Poweshiek	Constructed	2.4	8.0	13	1046	77.7	9.7	Fair
7	Beaver Lake	Dallas	Constructed	2.9	9.6	33	1009	30.1	3.1	Fair
9	Big Creek Lake	Polk	Constructed	5.5	18.1	864	46822	54.2	3.0	Fair
15	Browns Lake	Woodbury	Oxbow	1.4	4.5	220	6060	27.5	6.1	Fair
16	Brushy Creek Lake	Webster	Constructed	7.8	25.5	710	56318	79.3	3.1	Fair
18	Casey Lake (Hickory Hills Lake)	Tama	Constructed	3.2	10.7	39	742	18.9	1.8	Fair
19	Center Lake	Dickinson	Natural	3.0	9.7	280	612	2.2	0.2	Fair
20	Central Park Lake	Jones	Constructed	2.4	8.0	25	370	15.0	1.9	Fair
21	Clear Lake	Cerro Gordo	Natural	2.9	9.4	3669	9538	2.6	0.3	Fair
22	Cold Springs Lake	Cass	Constructed	2.2	7.1	16	21	1.3	0.2	Fair

ID	Name	County	Type	Avg. Depth (m)	Avg. depth (ft)	Lake Area (acres)	Watershed Area (acres)	Watershed to Lake Area Ratio	Watershed to Lake Volume Ratio	Water quality rating
24	Crawford Creek Impoundment	Ida	Constructed	3.5	11.6	58	2380	40.7	3.5	Fair
28	DeSoto Bend Lake	Harrison	Oxbow	2.7	8.9	854	12477	14.6	1.6	Fair
29	Diamond Lake	Poweshiek	Constructed	2.7	8.7	96	2673	27.9	3.2	Fair
33	East Okoboji Lake	Dickinson	Natural	3.2	10.4	1843	11779	6.4	0.6	Fair
34	Easter Lake	Polk	Constructed	3.4	11.2	185	6368	34.5	3.1	Fair
37	Fogle Lake	Ringgold	Constructed	2.8	9.2	39	509	13.1	1.4	Fair
41	Green Valley Lake	Union	Constructed	2.7	8.9	420	4756	11.3	1.3	Fair
42	Greenfield Lake	Adair	Constructed	3.1	10.1	53	941	17.9	1.8	Fair
43	Hannen Lake	Benton	Constructed	2.8	9.0	37	566	15.5	1.7	Fair
44	Hawthorn Lake (Barnes City Lake)	Mahaska	Constructed	3.5	11.5	185	3106	16.8	1.5	Fair
45	Hickory Grove Lake	Story	Constructed	4.8	15.9	82	3955	48.0	3.0	Fair
46	Hooper Area Pond	Warren	Constructed	2.6	8.5	396			0.0	Fair
49	Kent Park Lake	Johnson	Constructed	2.3	7.5	26	669	25.5	3.4	Fair
51	Lake Ahquabi	Warren	Constructed	3.0	9.8	116	1729	14.9	1.5	Fair
52	Lake Anita	Cass	Constructed	3.8	12.4	178	2317	13.0	1.1	Fair
53	Lake Cornelia	Wright	Natural	2.3	7.7	247	741	3.0	0.4	Fair
56	Lake Hendricks	Howard	Constructed	2.4	7.7	45	1164	26.0	3.4	Fair
57	Lake Icaria	Adams	Constructed	3.4	11.2	695	16808	24.2	2.2	Fair
58	Lake Iowa	Iowa	Constructed	3.5	11.6	81	1295	15.9	1.4	Fair
59	Lake Keomah	Mahaska	Constructed	3.1	10.1	77	1875	24.4	2.4	Fair
61	Lake Macbride	Johnson	Constructed	4.8	15.8	870	16163	18.6	1.2	Fair
62	Lake Meyer	Winneshiek	Constructed	3.5	11.6	34	1490	44.2	3.8	Fair
64	Lake Minnewashta	Dickinson	Natural	0.9	2.8	118	288	2.4	0.9	Fair
65	Lake of the Hills	Scott	Constructed	3.0	9.8	54	1650	30.7	3.1	Fair
70	Lake Sugema	Van Buren	Constructed	3.6	11.9	648	10657	16.4	1.4	Fair
72	Little River Watershed Lake	Decatur	Constructed	4.4	14.3	753	12552	16.7	1.2	Fair
78	Lower Gar Lake	Dickinson	Natural	0.9	2.8	264	10506	39.9	14.2	Fair
80	Manteno Park Pond	Shelby	Constructed	2.0	6.7	13	2253	173.3	26.0	Fair
82	Meadow Lake	Adair	Constructed	3.1	10.2	34	778	22.7	2.2	Fair
83	Meyers Lake	Black Hawk	Surface Mines	2.2	7.2	25	68	2.8	0.4	Fair
84	Mill Creek Lake	Obrien	Constructed	1.4	4.7	30	3564	117.6	25.2	Fair
85	Mitchell Lake	Black Hawk	Surface Mine	7.2	23.6	13	4	0.3	0.0	Fair
90	North Twin Lake	Calhoun	Natural	3.0	9.9	457	2097	4.6	0.5	Fair
92	Otter Creek Lake	Tama	Constructed	3.0	9.8	64	980	15.4	1.6	Fair
97	Prairie Rose Lake	Shelby	Constructed	2.3	7.6	190	4450	23.4	3.1	Fair
99	Red Haw Lake	Lucas	Constructed	4.4	14.6	73	947	13.0	0.9	Fair

ID	Name	County	Type	Avg. Depth (m)	Avg. depth (ft)	Lake Area (acres)	Watershed Area (acres)	Watershed to Lake Area Ratio	Watershed to Lake Volume Ratio	Water quality rating
103	Rodgers Park Lake	Benton	Constructed	2.2	7.2	21	2029	96.8	13.4	Fair
110	South Prairie Lake	Black Hawk	Surface Mine	2.9	9.4	24	61	2.5	0.3	Fair
111	Spring Lake	Greene	Surface Mine	0.8	2.8	50	469	9.3	3.4	Fair
112	Springbrook Lake	Guthrie	Constructed	2.5	8.2	14	1625	119.6	14.6	Fair
119	Twelve Mile Creek Lake	Union	Constructed	4.6	15.1	636	14020	22.0	1.5	Fair
121	Upper Gar Lake	Dickinson	Natural	1.2	3.8	38	216	5.7	1.5	Fair
123	Viking Lake	Montgomery	Constructed	4.7	15.5	144	2023	14.0	0.9	Fair
124	Volga Lake	Fayette	Constructed	3.2	10.6	132	5954	45.0	4.2	Fair
126	West Lake (Osceola)	Clarke	Constructed	4.3	14.1	308	5902	19.1	1.4	Fair
127	White Oak Lake	Mahaska	Constructed	2.6	8.4	18	569	32.4	3.8	Fair
130	Wilson Park Lake	Taylor	Constructed	2.8	9.3	16	146	8.9	1.0	Fair
131	Windmill Lake	Taylor	Constructed	3.1	10.2	24	549	23.1	2.3	Fair
2	Arrowhead Pond	Pottawattamie	Constructed	2.2	7.3	15	1032	68.6	9.3	Poor
4	Avenue of the Saints Lake	Bremer	Surface Mine	1.9	6.3	39	5676	144.1	22.8	Poor
5	Badger Creek Lake	Madison	Constructed	3.2	10.4	245	11157	45.5	4.4	Poor
6	Badger Lake	Webster	Constructed	2.0	6.6	43	12535	292.2	44.2	Poor
8	Beeds Lake	Franklin	Constructed	2.6	8.7	98	20374	207.7	24.0	Poor
11	Black Hawk Lake	Sac	Natural	1.5	5.0	919	13179	14.3	2.9	Poor
12	Blue Lake	Monona	Oxbow	1.4	4.6	264	5027	19.0	4.1	Poor
13	Bob White Lake	Wayne	Constructed	1.6	5.4	98	3456	35.4	6.6	Poor
14	Briggs Woods Lake	Hamilton	Constructed	3.7	12.0	59	7151	120.7	10.0	Poor
17	Carter Lake	Pottawattamie	Oxbow	2.6	8.5	314	2398	7.6	0.9	Poor
25	Crystal Lake	Hancock	Natural	1.4	4.7	264	1984	7.5	1.6	Poor
30	Dog Creek Lake	Obrien	Constructed	3.0	9.8	29	2839	96.6	9.9	Poor
31	Don Williams Lake	Boone	Constructed	5.2	16.9	152	21069	138.5	8.2	Poor
32	East Lake (Osceola)	Clarke	Constructed	2.1	7.0	13	297	22.7	3.2	Poor
35	Eldred Sherwood Lake	Hancock	Constructed	2.8	9.3	21	2138	101.8	11.0	Poor
36	Five Island Lake	Palo Alto	Natural	1.1	3.5	964	7726	8.0	2.3	Poor
47	Indian Lake	Van Buren	Constructed	1.6	5.2	49	345	7.0	1.3	Poor
48	Ingham Lake	Emmet	Natural	1.9	6.2	357	916	2.6	0.4	Poor
54	Lake Darling	Washington	Constructed	2.7	8.9	268	12451	46.5	5.2	Poor
60	Lake Manawa	Pottawattamie	Oxbow	1.4	4.4	733	2425	3.3	0.7	Poor
63	Lake Miami	Monroe	Constructed	3.0	9.7	138	3871	28.0	2.9	Poor
66	Lake of Three Fires	Taylor	Constructed	2.5	8.3	94	3620	38.4	4.6	Poor
67	Lake Orient	Adair	Constructed	1.8	6.0	27	584	22.0	3.7	Poor
68	Lake Pahoja	Lyon	Constructed	3.3	10.7	66	3856	58.0	5.4	Poor
69	Lake Smith	Kossuth	Constructed	1.7	5.4	56	1418	25.3	4.7	Poor
74	Little Spirit Lake	Dickinson	Natural	1.8	6.0	604	1444	2.4	0.4	Poor
75	Little Wall Lake	Hamilton	Natural	1.6	5.3	246	187	0.8	0.1	Poor

ID	Name	County	Type	Avg. Depth (m)	Avg. depth (ft)	Lake Area (acres)	Watershed Area (acres)	Watershed to Lake Area Ratio	Watershed to Lake Volume Ratio	Water quality rating
76	Littlefield Lake	Audubon	Constructed	2.4	8.0	56	2445	43.3	5.4	Poor
77	Lost Island Lake	Palo Alto	Natural	3.1	10.3	1151	5123	4.5	0.4	Poor
79	Lower Pine Lake	Hardin	Constructed	1.8	6.0	58	944	16.4	2.7	Poor
81	Mariposa Lake	Jasper	Constructed	2.4	7.8	17	576	33.0	4.2	Poor
93	Ottumwa Central Park Ponds	Wapello	Oxbow	1.7	5.6	72	2229	30.9	5.5	Poor
94	Pierce Creek Lake	Page	Constructed	1.7	5.6	36	2758	76.9	13.6	Poor
101	Roberts Creek Lake	Marion	Constructed	2.7	8.8	296	7811	26.4	3.0	Poor
102	Rock Creek Lake	Jasper	Constructed	2.6	8.6	595	26071	43.8	5.1	Poor
107	Silver Lake (Delaware)	Delaware	Constructed	2.0	6.4	37	201	5.4	0.8	Poor
105	Silver Lake (Dickinson)	Dickinson	Natural	1.8	6.1	1068	15209	14.2	2.3	Poor
108	Silver Lake (Palo Alto)	Palo Alto	Natural	1.4	4.7	648	8309	12.8	2.8	Poor
106	Silver Lake (Worth)	Worth	Natural	1.5	4.8	315	1729	5.5	1.2	Poor
113	Storm Lake	Buena Vista	Natural	2.3	7.6	3142	14701	4.7	0.6	Poor
114	Swan Lake	Carroll	Natural	1.3	4.3	141	745	5.3	1.2	Poor
115	Thayer Lake	Union	Constructed	2.0	6.4	14	494	35.6	5.5	Poor
117	Trumbull Lake	Clay	Natural	0.9	3.1	1171	46838	40.0	13.0	Poor
118	Tuttle Lake	Emmet	Natural	1.1	3.6	2268	122737	54.1	14.9	Poor
120	Union Grove Lake	Tama	Constructed	1.9	6.1	115	6834	59.3	9.7	Poor
122	Upper Pine Lake	Hardin	Constructed	2.2	7.3	85	8690	102.4	14.1	Poor
128	Williamson Pond	Lucas	Constructed	2.5	8.1	28	1472	52.8	6.5	Poor

Appendix 2. Selected lake and basin characteristics of 127 lakes included in the DNR lake-classification study excluding Coralville, Rathbun, Red Rock and Saylorville reservoirs.

	Good	Fair	Poor
Number of Lakes	22	58	47
Watershed Area:Lake Area ratio	20.3	28.8	47.5
Mean Depth (m)	4.4	3.1	2.2
Mean Depth (ft)	14.5	10.2	7.1
Watershed Area:Lake Volume ratio (acre/acre-ft)	1.7	3.5	6.5